

addressing the rejections and comparing the claims with the applied prior art, the important features of the invention will be discussed in general to provide a background.

3) The present invention, in a general sense, is characterized by the following features A) to E).

A) Solid carbon is placed directly into a crucible or boat together with a compound raw material and  $B_2O_3$  (see e.g. claim 1).

B) The solid carbon in the crucible is in contact with the  $B_2O_3$  while the  $B_2O_3$  is in a melted state (see e.g. claims 1 and 2), and the  $B_2O_3$  preferably further contains water (see e.g. claim 4).

C) The carbon concentration in the finished compound semiconductor crystal, such as a GaAs crystal, is adjusted by adjusting the amount of solid carbon that is placed into the crucible (see e.g. claim 22).

D) The amount of solid carbon placed into the crucible is greater than the amount of carbon that is doped into the resulting compound semiconductor crystal (see e.g. claim 6).

E) The carbon concentration in the finished compound semiconductor crystal may also be adjusted by altering the surface area ratio of the solid carbon placed into the crucible, for example by providing the solid carbon alternatively in the form of a powder, fibers, or a bulk solid, or the like (see e.g. claims 12 to 18).

- 4) The primary feature of the invention, identified above as feature A), is that solid carbon is placed directly into a crucible together with a compound semiconductor raw material and  $B_2O_3$ .

As a result, the solid carbon, the compound semiconductor raw material, and the  $B_2O_3$  will all be together in the crucible, when the compound raw material is melted. Particularly, the solid carbon is brought into contact with melted  $B_2O_3$  which further contains water (see feature B) above). In the process, the solid carbon will react with the water in the  $B_2O_3$  so as to become dissolved into the raw material melt. Therefore, the direct contact between the solid carbon and the melted  $B_2O_3$ , as well as the water content in the  $B_2O_3$ , are directly related to the reaction and dissolution of the carbon in the raw material melt.

The semiconductor raw material placed into the crucible according to the invention is a compound raw material, such as GaAs, for example in the form of a polycrystal, and not an elemental raw material such as Ga and As individually. Moreover, this compound semiconductor raw material is placed into the crucible (e.g. in solid form) and is later heated and melted in the crucible, together with the solid carbon and the boron oxide. Problems will arise if these features of the invention are not carried out, as will be discussed below.

- 5) It should be noted that the carbon concentration in the finished crystal is not controlled by the water concentration in the boron oxide, according to the invention. Quite distinctly in the method of the invention, the water in the  $B_2O_3$  facilitates the dissolution reaction of the solid carbon into the raw material melt.

- 6) Instead of focussing on the control of the water concentration to control the carbon concentration, the present invention makes use of and refines the discovery that not all of the solid carbon will be melted, dissolved, and ultimately doped into the crystal that is being formed.

The present inventors have discovered that only a very small portion, e.g. less than one tenth (see claim 7), of the amount of solid carbon introduced into the crucible is ultimately doped into the crystal. It is believed that this partial and only minimal dissolution of the carbon results due to a very slow reaction rate of the carbon dissolution, or due to chemical equilibrium limitations of the raw material solution. Thus, according to the invention, an excess amount of carbon is placed into the crucible, i.e. a greater amount of carbon is placed into the crucible than the amount of carbon that is desired to be doped into the finished crystal. There is a relationship between the excess amount of carbon in the crucible and the dopant amount of carbon ultimately being introduced into the crystal, so that the carbon concentration in the finished crystal can be adjusted by adjusting the excess amount of solid carbon placed into the crucible (see feature C) above). Since these features were not previously realized or utilized in the prior art, the proper adjustment of the amount of solid carbon being placed into the crucible is not mere routine optimization by a person of ordinary skill.

Furthermore, the carbon concentration in the crystal can be adjusted by controlling the dissolution rate of carbon in the crucible, by providing the solid carbon in different forms having different surface area ratios (see feature E) above). For example, if a powder form of solid carbon is provided, then the

dissolution of carbon progresses more quickly and more completely, so the carbon concentration resulting in the solid crystal will be higher, than if solid bulk pieces of carbon are provided instead. The carbon concentration in the crystal can also be controlled by controlling the time allowed for the dissolution to take place before begin the crystal formation.

- 7) The above discussed features of the invention are contrary to the general understandings in the art at the time the invention was made, and also are contrary to the teachings of the prior art references applied by the Examiner.

Most generally, the understanding in the art is that the entire amount of an element (such as Si for example) added into the raw material melt will be dissolved into the raw material melt, and ultimately this entire amount of the added element will be introduced into the crystal being formed. That is not true of carbon introduced into the melt; and this feature is purposely used according to the invention.

Generally also, conventional knowledge in the art involves external sources of carbon located separately from the melt, rather than placing solid carbon directly into the crucible for achieving carbon doping into the crystal being formed.

In this context, the water concentration in the  $B_2O_3$  encapsulant has been used conventionally to indirectly control the carbon concentration, because the water has a gettering effect of removing carbon from the melt. The invention avoids the need of such indirect carbon control by directly adjusting the amount of solid carbon that is physically placed into the crucible.

- 8) Also, the references applied by the Examiner do not suggest to place a compound semiconductor raw material, such as compound GaAs, into the crucible, and then melt this compound semiconductor raw material together with the solid carbon.

Instead, the references either place a pre-melted liquid compound semiconductor raw material into the crucible (see e.g. U. S. Patent 5,515,810 - Yamashita), or place separate non-compounded elemental semiconductor raw materials, such as separate raw materials of Ga and As, into the crucible (see e.g. JP 1-037833 - Yamamoto). Both of the conventional teachings are problematic.

When two individual raw materials of Ga and As are melted and combined to produce a GaAs melt, the combining reaction will be vigorous and a temperature increase will result. Such a vigorous reaction would result in intensive evolution of gas with associated bubbling and churning of the melt, whereby any solid carbon would be gasified or blown out of the crucible and thereby completely or partially lost from the melt.

On the other hand, when a pre-melted liquid compound of GaAs is used, it is not possible to add solid carbon into the crucible, because a sudden vigorous reaction between the hot pre-melted liquid GaAs and the solid carbon would similarly result in gas evolution, churning and bubbling, and thereby disrupt the proper smooth reaction and dissolution of carbon into the melt.

For these reasons, the invention calls for placing solid carbon and compound raw material into the crucible and thereafter melting the raw material and carbon in the crucible.

- 9) Referring now to section 2 on pages 2 to 4 of the Office Action, the rejection of claims 1, 3 to 6, 10, 19, 20 and 22 as obvious

over U. S. Patent 5,518,810 (Yamashita) in view of Japanese Patent 01-037833 (Yamamoto) is respectfully traversed. To provide a better understanding of the true disclosure of the Yamamoto reference, of which the Examiner referred only to an English abstract, applicants are enclosing an English translation of two portions of the Yamamoto reference (note that Japanese Patent Laying-Open No. 64-37833 corresponds to JP 01-037833).

- 10) Present independent claim 1 is directed to a method of preparing a carbon doped group III - V compound semiconductor crystal, comprising a step of placing a compound raw material, solid carbon, and a boron oxide substance together into a crucible or boat, and then heating and melting the compound raw material in the crucible or boat in which the solid carbon and boron oxide substance are also contained. The general significance of these features as recited in claim 1 has been discussed above. The applied combination of Yamashita in view of Yamamoto would not have suggested the presently claimed combination of method steps.
- 11) Yamashita discloses a method of producing a GaAs crystal containing carbon, whereby the carbon is introduced into the melt and into the crystal by a completely different concept and completely different mechanism than that of the present invention.

Contrary to the present invention, Yamashita does **not** place solid carbon directly into the crucible together with the semiconductor raw material and the boron oxide encapsulant. Instead, Yamashita provides carbon in the form of gaseous carbon monoxide (CO) emitted from a carbon heater, into and through the  $B_2O_3$  encapsulant, and from there into the melt. Since Yamashita goes to such complicated measures of providing and controlling gaseous

carbon, for example by applying coatings onto the carbon heater and controlling water concentrations to two different levels in two different melt pools, there would have been no suggestion that it would even be possible to place solid carbon directly into the crucible. If that would have been considered possible, the entire complicated teachings of Yamashita would have been unnecessary.

Yamashita also does not disclose or suggest the presently claimed step of placing a (solid) compound semiconductor raw material into the crucible, and then heating and melting the compound raw material in the crucible. Instead, Yamashita places a pre-melted liquid GaAs raw material into the crucible (see e.g. abstract, line 13; col. 2, lines 8 and 22 to 23; etc.). Since Yamashita places a pre-melted liquid compound semiconductor raw material into the crucible, it would not have been suggested to first place a solid raw material in the crucible and then carry out melting of the raw material in the crucible as presently claimed. By placing a pre-melted liquid raw material in the crucible, it would also not have been suggested to place a solid carbon material into the crucible, because that would have produced an uncontrolled reaction between the solid carbon and pre-melted liquid semiconductor raw material.

Moreover, Yamashita would have provided no teaching or suggestion of how to control the dissolution reaction of solid carbon placed directly into the crucible. Instead, Yamashita teaches that the carbon concentration is controlled by applying a proper coating onto the carbon heater and by properly controlling the water concentration in the  $B_2O_3$  encapsulant, since the carbon is provided in the form of CO gas emitted from the carbon heater and then dissolved into the  $B_2O_3$ , and from there ulti-

mately mixed into the GaAs melt (col. 2, line 61 to col. 3, line 5).

- 12) The Examiner recognizes that Yamashita does not disclose or suggest a step of placing solid carbon into the crucible. For such an alleged teaching, the Examiner turns to the Yamamoto reference. As noted by the Examiner, fines of carbon are introduced into a crucible together with Ga, As and  $B_2O_3$ , and these substances are then melted. The Examiner suggests that it would have been obvious to modify the above discussed Yamashita method by introducing solid carbon into the crucible according to the teachings of Yamamoto. Applicants respectfully submit that there would have been no motivation to combine the teachings as proposed by the Examiner, and even if so combined, the present invention would not have been suggested.
- 13) As discussed above, Yamashita teaches placing pre-melted liquid semiconductor raw material into the crucible, while introducing the carbon via CO gas emitted by a carbon heater. If, instead, the carbon were introduced in the form of a solid carbon powder according to Yamamoto, in combination with the pre-melted liquid semiconductor material in the method of Yamashita, an uncontrolled reaction of the solid carbon and pre-melted liquid semiconductor raw material would have resulted. Therefore, a person of ordinary skill in the art would not have been motivated to try to introduce solid carbon according to Yamamoto into a pre-melted liquid semiconductor material according to Yamashita, as proposed by the Examiner.



- 14) Even if the teachings of the references were to be combined as proposed by the Examiner, the present invention would not have been suggested.

As discussed above, Yamashita suggests the use of a pre-melted GaAs compound semiconductor raw material. On the other hand, Yamamoto suggests introducing separate individual non-compound elemental solid raw materials of Ga and As into the crucible, and then melting the two individual solid raw materials to form a GaAs melt. Thus, neither one of the references suggests placing a (solid) compound semiconductor raw material into the crucible and then melting that compound raw material in the crucible. In other words, the present invention requires previously forming a compound raw material such as GaAs in a solid condition, which is then later melted within the crucible. Contrary thereto, Yamashita suggests providing a pre-melted compound raw material, and Yamamoto suggests providing two separate individual raw materials of Ga and As which are then melted together to form a GaAs melt.

Even if the teachings of both references are considered together, the compound raw material will only exist in the melted state (in Yamashita it's already pre-melted; and in Yamamoto it only becomes a compound after it is melted). As discussed above, when melting and then combining individual Ga and As raw materials, there will be a vigorous reaction and the temperature will increase and gas will be evolved. When combining solid carbon with pre-melted liquid raw material, an uncontrollable or intensive reaction will also result. Thus, solid carbon would be blown out of the crucible or converted into a gas.

In contrast, the use of a solid compound material as a starting material according to the invention, will avoid such

excessive reactions and instead achieve a more gentle, uniform, and consistent dissolution of the raw material and the solid carbon. Neither reference provides any suggestion toward initially providing the compound material in a solid state, and thereafter melting the compound material in the crucible. It is this provision of the solid compound raw material which is later melted in the crucible together with the solid carbon and the  $B_2O_3$  encapsulant, that makes the method of the present invention functionally possible. The intensive and uncontrollable reactions that would occur by trying to combine the teachings of the references as proposed by the Examiner, would have made the Examiner's proposed combination unworkable.

- 15) The rejected claims dependent from claim 1 recite additional features that further distinguish the invention over the combination of Yamashita in view of Yamamoto, as follows.
- 16) Present claim 6 recites that the amount of solid carbon placed into the crucible is greater than the amount of carbon that is ultimately doped into the compound semiconductor crystal that is formed by the process. In other words, not all of the carbon that is initially placed into the crucible ends up in the finished crystal.

In this context, the Examiner states that Yamashita discloses that "*the carbon concentration (in the melt) is adjusted to the target concentration in the crystal (see column 9, lines 14 to 17)*". This disclosure of the reference, as identified by the Examiner, would suggest that the carbon concentration in the melt is equal to the target concentration in the crystal. That is directly contrary to present claim 6.

This should be further considered in view of the ordinary understanding in the art that elemental components that are directly placed into the crucible and melted into a raw material melt are generally completely incorporated into the crystal being formed. As discussed above, such a general understanding does not hold true for solid carbon that is placed into the crucible according to the invention.

As can be seen in the enclosed partial translation of the Yamamoto reference, it could be expected that the same amount of carbon as introduced into the crucible will ultimately be introduced into the crystal being formed. Namely, Yamamoto teaches that "a predetermined amount" of carbon is placed into the crucible, and then melted into the other raw materials. Then, "*Since a predetermined amount of carbon is dissolved in the GaAs melt, a predetermined amount of carbon according to the segregation coefficient can be included in the crystal*" (see paragraph (1) of the first translation portion).

- 17) Present claim 22 depending from claim 6 further makes clear that the amount of solid carbon placed into the crucible, while being greater than the amount of carbon ultimately doped into the finished crystal, can be adjusted so as to adjust the amount of carbon being doped into the crystal. In view of the above, the references do not suggest such a relationship of adjusting the amount of carbon in the crucible so as to adjust the amount of carbon introduced into the crystal, whereby the amount of carbon in the crucible is greater than that introduced into the crystal. The Examiner asserts that Yamamoto discloses "*adding a fixed quantity or more carbon to a GaAs crystal*". However, the only teaching of the Yamamoto abstract referred to by the Examiner is

that the carbon concentration can be more than the Si concentration, but this teaches nothing about the amount of carbon in the crucible vs. the amount of carbon in the finished crystal.

- 18) For the above reasons, the Examiner is respectfully requested to withdraw the rejection of claims 1, 3 to 6, 10, 19, 20 and 22 as being obvious over Yamashita in view of Yamamoto.
- 19) Referring to section 3 on page 4 of the Office Action, the rejection of claims 2, 10, 11 and 21 as obvious over Yamashita in view of Yamamoto and further in view of U. S. Patent 5,131,975 (Bourret-Courchesne) is respectfully traversed. Since claims 2, 10, 11 and 21 depend from claim 1, the above discussion of claim 1 and the Yamashita and Yamamoto references applies here as well. The additional features of claims 2, 10, 11 and 21 further distinguish the invention over the prior art.
- 20) Present claim 2 depends from claim 1 and further recites a step of heating and melting the boron oxide substance and having the melted boron oxide substance in contact with the solid carbon, during the step of heating and melting the compound raw material. In other words, both the compound semiconductor raw material and the boron oxide are melted during the same time, and at least a portion of the solid carbon still exists and is in contact with the melted boron oxide. The proposed combination of references does not suggest such a step or sequence of steps as recited in present claim 2.
- 21) Yamashita does not suggest anything about placing solid carbon into the crucible. Yamamoto does not teach anything about melt-

ing the semiconductor raw material and the boron oxide, but maintaining at least some of the carbon in the solid state, so that this solid carbon can be in contact with the melted boron oxide. Moreover, Yamamoto does not suggest providing and then melting a compound semiconductor raw material.

The Examiner asserts that Yamashita and Yamamoto "*show all the limitations, except that the  $B_2O_3$  should be heating and melted before contact the carbon*". For the above reasons, it is submitted that the Examiner's assertion is incorrect. Moreover, it is noted that present claim 2 does not require that the  $B_2O_3$  must be melted before contacting the carbon. Instead, the contact between the solid carbon and the  $B_2O_3$  can already be established before melting the  $B_2O_3$ , and claim 2 simply requires that the melted boron oxide be in contact with at least a portion of the solid carbon, which of course can occur after the carbon and unmelted boron oxide have been placed into contact.

- 22) The Examiner turns to Bourret-Courchesne for teaching a sequence of heating steps that first melt the  $B_2O_3$  and then melt the raw material. There is no suggestion by Bourret-Courchesne in relation to providing contact between a melted boron oxide substance and a solid carbon substance that has been placed into the crucible. Therefore, the Bourret-Courchesne reference seems inapplicable. Namely, the Bourret-Courchesne reference is completely silent about any particular method of adding carbon into the crucible, so that there would have been no suggestion toward the presently claimed combination of steps of placing solid carbon into a crucible together with a compound raw material and a boron oxide substance, and then melting the raw material and the boron

oxide substance while having the melted boron oxide substance in contact with at least a portion of the solid carbon.

- 23) Present claims 10 and 11 depend from claim 1 and recite that the melted raw material is maintained in a melted state for a certain time period, and particularly a time period of 3 to 72 hours, before solidifying the raw material to grow the crystal. This time period of maintaining the melted condition is carried out according to the invention for allowing the carbon dissolution reaction to occur, whereby the time period can be controlled so as to control the carbon concentration that will result in the crystal that is being formed.

While the Examiner asserts that the raw material is kept in the melted state for some time to allow reaction to occur in the prior art reference, there is no express teaching that the melt should be maintained in a molten state for 3 to 72 hours before beginning the crystal solidification. Instead, it appears that as soon as the raw material is completely molten, the seed crystal growth is commenced (see e.g. col. 4, lines 8 to 15).

- 24) Present claim 21 depends from claim 2 and further recites that the melted boron oxide substance is in contact with the melted compound raw material, in addition to being in contact with the solid carbon as recited in claim 2. Thus, the melted boron oxide contacts both the solid carbon and the melted raw material. The Examiner has not addressed such a combination of features.
- 25) For the above reasons, the Examiner is respectfully requested to withdraw the rejection of claims 2, 10, 11 and 21 as obvious over Yamashita in view of Yamamoto and Bourret-Courchesne.

26) Referring to section 4 on pages 5 to 6 of the Office Action, the rejection of claims 6 to 9 and 23 as obvious over Yamashita in view of Yamamoto is respectfully traversed. The Examiner has identified the salient features of claims 6 to 9, which depend from claim 1. The Examiner has also admitted that Yamashita and Yamamoto do not disclose these features recited in claims 6 to 9. The Examiner simply asserts that it would have been obvious to carry out routine experimentation to determine optimum parameters for heat treating the carbon prior to placing it into the crucible, and to determine the amount of carbon that should be placed into the crucible.

It is respectfully submitted that the Examiner's point would only apply to the present situation if the prior art would provide some suggestion, in the first place, to carry out any sort of heat treatment of solid carbon that is to be placed into the crucible, and a suggestion that the amount of carbon placed into the crucible will be greater than the amount of carbon doped into the crystal. Only after such suggestions are provided in the prior art could a person of ordinary skill be expected to carry out further optimizing experimentation, if at all.

The Examiner has shown no such suggestions in the prior art, so that a person of ordinary skill in the art would have found no motivation to take the next step and try to carry out experiments to find optimum parameters. In other words, if there is no suggestion toward a certain feature, then it is impossible to simply "optimize" the parameters of such a feature.

The only reference used by the Examiner to show placing solid carbon into the crucible is Yamamoto, and Yamamoto does not suggest heat treatment before placing the carbon into the crucible. The particular conditions for carrying out such a heat

treatment, as presently claimed, cannot simply be extrapolated from thin air. There is also no suggestion in the references that the amount of carbon placed into the crucible is, e.g. ten times, greater than the amount of carbon that will be doped into the crystal.

- 27) The Examiner has not addressed claim 23. Claim 23 recites that the method of claim 1 is carried out so that the finished semiconductor crystal has a very uniform carbon concentration, specifically that the variation in the carbon concentration is not more than 8 1/3% between a lowest carbon concentration and a highest carbon concentration. While Yamashita aims to achieve a uniform carbon concentration, the proposed method is a complicated one using a pre-melted raw material, and a gaseous transfer of CO to provide carbon into the melt. Even so, Yamashita indirectly refers to a variation or difference of 300% in the carbon concentration, namely a carbon concentration varying within the range of  $1 \times 10^{15}$  to  $4 \times 10^{15}$  (see e.g. col. 8, lines 10 and 60). Thus, it seems that the prior art method or methods are unable to achieve the very high degree of carbon concentration uniformity achieved by the present invention, as recited in claim 23.
- 28) For the above reasons, the Examiner is respectfully requested to withdraw the rejection of claims 6 to 9 and 23 as obvious over Yamashita in view of Yamamoto.
- 29) Referring to section 5 on page 7 of the Office Action, the rejection of claims 12 to 18 as obvious over Yamashita in view of Yamamoto is respectfully traversed.



As generally explained above in the background discussion, claims 12 to 18 recite providing different forms or types of solid carbon for the purpose of influencing the reaction rate of dissolution of the solid carbon in the raw material melt. The resulting influence on the concentration of carbon contained in the crystal being formed is an unobvious result, because the prior art would have provided no suggestion toward such a way of controlling the carbon concentration. Thus, the present invention has shown that the carbon concentration in the crystal can be controlled or adjusted by adjusting not only the amount of solid carbon placed into the crucible, but also the form or configuration of solid carbon placed into the crucible.

The only reference applied by the Examiner to show a step of placing solid carbon into the crucible is Yamamoto, and the Yamamoto reference provides no suggestion toward the presently claimed features and the unobvious results achieved thereby. The Examiner's assertion of "*expected beneficial results*" cannot be based on a *post hoc* reconstruction and rationalization in view of an understanding of the presently disclosed invention. The prior art provided no such expectation of beneficial results to be achieved.

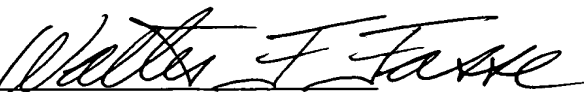
For the above reasons, the Examiner is respectfully requested to withdraw the rejection of claims 12 to 18 as obvious over Yamashita in view of Yamamoto.

30) Favorable reconsideration and allowance of the application,  
including present claims 1 to 23, are respectfully requested.

Respectfully submitted,

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WFF:ar/3442  
Encls.: postcard, partial  
translation of Yamamoto  
reference

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